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EFFECTS OF INFLAMMATION ON PEROXISOMAL ENZYME ACTIVITY, CATALAS--ETC(U)
FEB 77 P G CANONICO, W RILL, E AYALA

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Effects of Inflammation on Peroxisomal Enzyme Activity,
Catalase Synthesis and Lipid Metabolism

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In conducting the research described in this report, the investigators adhered to the "Guide for the Care and Use of Laboratory Animals," as promulgated by the Committee on the Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Research Council. The facilities are fully accredited by the American Association for Accreditation of Laboratory Animal Care.

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RUNNING TITLE

INFLAMMATION AND HEPATIC PEROXISOMES

ABSTRACT

The activity of hepatic peroxisomal enzymes, catalase, urate oxidase, D-amino acid oxidase, hydroxy acid oxidase, and carnitine acetyltransferase were serially measured following a turpentine-induced sterile inflammatory lesion in rats. The ensuing depression in peroxisomal enzyme activities was shown to be temporally related to development of the acute inflammatory response indicating that depression of peroxisomal activity is a nonspecific host response to inflammation.

Measurements of the rate of degradation and synthesis of catalase showed that the decrease in catalase activity results from a 60 per cent decrease in its rate of synthesis. These data suggest that during acute inflammation, hepatic peroxisomal protein synthesis may be expendable or subordinate to synthesis and release by the liver of acute-phase serum proteins.

Hepatocytes isolated from turpentine-treated rats showed, respectively, decreased and increased capacity for lipid oxidation and fatty acid esterification. These results, which demonstrate the existence of an inverse relationship between hepatic peroxisomal content and lipid metabolism during inflammation, are analogous to the known relationship between liver peroxisomal proliferation and drugs which lower serum cholesterol and triglycerides.

Additional key words: Nafenopin, clofibrate, hypolipidemic drugs, acute-phase proteins, liver cells, infection.

INTRODUCTION

The name peroxisome designates a special type of intracellular respiratory particle characterized by the association of one or more H_2O_2 generating oxidases with large amounts of catalase (16). In a recent biochemical and morphometric study we reported that pneumococcal sepsis caused a marked reduction in the number of peroxisomes of rat liver cells and in the activity of two marker enzymes, catalase and urate oxidase (8).

A decrease in catalase activity has also been shown to accompany subcutaneous injury (34) and hepatectomy (23), and while the latter also induces a concomitant loss in activity of other peroxisomal enzymes, it is not known if hepatic depression of peroxisomal enzymes represents a generalized nonspecific response of the host to inflammatory stress. In the present study, a sterile inflammatory lesion was induced by subcutaneous injection of turpentine in normal rats as well as in rats treated with the peroxisomal proliferating drug, nafenopin. The activity of hepatic peroxisomal enzymes were then serially measured and the results temporally related with expression of known acute-phase reactants. The resulting pattern of change in the activity of peroxisomal enzymes was found to be consistent with development of the acute inflammatory response, suggesting that depression of peroxisomal activity is another nonspecific host response to inflammation.

While the decrease in peroxisomal enzyme activity following tissue injury has been correlated with a decrease in enzyme protein (24, 33) it is not known if the change represents decreased synthesis, increased degradation, or both. Hence, kinetic measurements of hepatic catalase degradation and synthesis were made using, for the former, allylisopropylacetamide to block catalase synthesis (41), and for the

latter, aminotriazole to inactivate specifically pre-existing catalase (41). Results indicate that the decrease in catalase activity during acute inflammation stems primarily from reduced synthesis of the enzyme.

Since a role for peroxisomes in lipid metabolism has been proposed (4, 15, 43), hepatocytes were isolated from control and turpentine-treated rats and their capacity for fatty acid oxidation and esterification evaluated. Results are discussed with respect to known alterations in lipid metabolism during infection and inflammation.

MATERIALS AND METHODS

ANIMALS AND SAMPLE PREPARATIONS

Male, Fisher-Dunning rats weighing 200-250 gm., housed in light-temperature-controlled quarters, were fed rat chow and water ad libitum. Rectal temperatures were monitored twice daily with a Yellow Springs Telethermometer. Rats were inoculated subcutaneously, at the nape of the neck, with turpentine at a dose of 2.5 ml./kg. body weight. Control rats, designated Day 0, were killed within 15 min. following the injection of turpentine. The remaining rats were killed, in groups of five, at selected 24-hour intervals. For collection of tissue samples, rats were anesthetized with Halothane (Ayerst Laboratories), the abdominal cavity was opened and 3 to 4 ml. of blood were collected from the inferior vena cava by venipuncture with a heparinized syringe. An aliquot of blood was taken for total and differential leukocyte counts, while the remaining blood was immediately cooled, centrifuged and the resulting plasma subsequently assayed for enzymatic activities, trace metals and α_2 -macroglobulin. The liver was excised, rinsed in 0.9 per cent NaCl, weighed and a portion homogenized in 3 volumes of 0.9 per cent

NaCl in a Brinkman polytron.

In a separate study, complete necropsy and microscopic examinations were performed on groups of three rats for up to 72 hours after turpentine inoculation.

CHEMICAL AND ENZYME ANALYSES

Hepatic catalase activity was assayed spectrophotometrically at 240 nm by measuring the rate of H_2O_2 decomposition (28). The first-order rate constant was calculated and converted to micromoles of H_2O_2 concentration of 37.5 μ mole/3 ml. of reaction mixture. Urate oxidase was assayed in borate-HCl buffer, pH 9.0, by following the oxidation of uric acid at 292 nm (26); D-amino acid oxidase and hydroxy acid oxidase were measured in sodium pyrophosphate buffer, pH 8.6, using D-alanine and glycolate as substrates, respectively. The resulting α -ketoacids were then quantitated by a reaction with 2-4-dinitrophenyl hydrazine (26). Carnitine-dependent acetyltransferase activity was determined by following the thiol reagent, 5', 5'-dithio-bis (2-nitrobenzoate), coupled release of CoA-SH at 412 nm (29). Peroxisomal enzyme activities are reported in milliunits/nanomoles of substrate converted per milligram of protein per minute.

Plasma zinc and iron (36) concentrations were determined by atomic absorption spectrophotometry. Lysozyme levels were measured by the lysoplate method of Osserman and Lawlor (35) while β -glucuronidase activity was determined as described by Canonico and Bird (6). α_2 -Macroglobulin was determined by the immunoprecipitation assay of Weimer and Benjamin (49).

Protein concentrations were assessed by an automated Lowry procedure using bovine serum albumin (BSA) as standard (27).

DRUG TREATMENTS

Nafenopin treated rats were maintained on a diet of powdered rat chow containing 0.1 per cent (w/w) nafenopin for 1 week prior to use. 3-Amino-1, 2, 4,-triazole (AT) was given as an aqueous (50 mg./ml.) intraperitoneal injection at a dose of 2 ml./100 gm. body weight. Solutions of allylisopropylacetamide (AIA), 25 mg./ml. water, were administered twice daily at a dose of 1 ml./100 gm. body weight. Where applicable, turpentine was given subcutaneously 12 hours after the initial injection of AIA and coincident with AT.

PREPARATION OF SINGLE CELL SUSPENSION OF HEPATOCYTES

Hepatic parenchymal cells (HPC) were isolated from nembutal (50 mg./100 gm. body weight) anesthetized rats by in situ perfusion of a solution of 0.03 per cent collagenase (Type II, Worthington Biochemicals), 1.5 per cent fatty acid free BSA (Fraction V, Sigma) and 50 µg./ml. Gentamicin (Schering Corp.) in Ca^{++} -free Krebs-Henseleit bicarbonate (K-H) buffer pH 7.4. The perfusion and subsequent processing of the liver was according to the method of Berry (3). HPC viability (typically 85-90 per cent viable) was assessed by trypan blue exclusion and the concentration of cells was adjusted to 3.5×10^7 HPC/ml. in K-H buffer containing 50 µg./ml. Gentamicin.

LIPID METABOLISM

The metabolism of fatty acids, complexed at a molar ratio of 2:1 with BSA was monitored by measuring their incorporation into cellular lipids and oxidation to CO_2 . Hepatocytes (3.5×10^6 in 1.5 ml. K-H buffer) were incubated in polypropylene tubes with 2 µCi. of the [$1\text{-}^{14}\text{C}$] labeled fatty acids. The reaction mixtures were gassed for 15 seconds with a mixture of 95 per cent O_2 and 5 per cent CO_2 , stoppered and incubated at 37° in a reciprocating water bath (160 osc./min.) for up to 60 minutes. Cellular

lipids were then extracted and quantitated by the method of Folch et al. (11). For fatty acid determinations reactions were terminated by injection of 0.5 ml. of 10 per cent trichloroacetic acid and after 30 minutes, radioactive CO_2 was measured on a Bactec R301 (Johnson Lab. Incorp., Cockeysville, Md.).

STATISTICS

Results obtained from days 1 to 5 turpentine-treated rats were compared to day 0 values and the statistical significance determined by Student's *t* test. The validity of this comparison was assured by initial studies which showed that saline-injected rats, pair-fed to turpentine-treated rats, did not differ from day 0 values in any of the measured parameters.

RESULTS

PATHOLOGY

Gross and microscopic observations revealed that the lesions significant to turpentine inoculation were the development of subcutaneous abscesses at the inoculation site, hepatic fatty changes and renal tubular changes. Subcutaneous turpentine inoculation sites progress from diffuse cellulitis characterized by liquifaction necrosis, edema, neutrophil and mononuclear cell infiltration 24 hours after inoculation to moderately well encapsulated abscesses by 72 hours. Compared with day 0 rats, minimal fatty changes were seen in periportal hepatocytes by 24 hours post-turpentine inoculation, increased by 48 hours and appeared to be reduced by 72 hours post-inoculation. In these studies the greatest fatty changes were only minimal to mild. Hyaline droplet changes were also observed in proximal convoluted tubules of all turpentine-inoculated rats.

RELATION OF THE INFLAMMATORY RESPONSE TO HEPATIC PEROXISOMAL ENZYME
ACTIVITIES

Biochemical and physiological responses to turpentine-induced inflammatory subcutaneous lesions are shown in Table 1. Fever occurred on day 1, while leukopenia was recorded on days 1 to 3. Consistent with development of acute-phase response to inflammation are the depression of plasma iron on day 1 and plasma zinc on days 1 to 3, as well as the appearance of acute-phase serum protein as depicted by α_2 -macroglobulin (MFP). Peak plasma MFP concentration, whose appearance in blood requires de novo transcription (46) and thus is indicative of de novo protein synthesis, occurred at 48 hours and was substantially reduced by 72 hours. Increasing concentrations of plasma lysozyme were consistent with development of an inflammatory lesion. Plasma β -glucuronidase, an enzyme proposed to be an indicator of hepatic cellular damage (7), showed only a small rise on day 1.

The hepatic peroxisomal enzymes, catalase, urate oxidase, D-amino acid oxidase and hydroxy acid oxidase manifested decreased activity following turpentine injection (Table 2). Catalase showed the greatest depression in activity (a 60 per cent decrease by day 3), urate oxidase, D-amino acid oxidase and hydroxy acid oxidase showed reductions of 35, 33 and 46 per cent, respectively.

Fluxes in carnitine acetyltransferase activity were measured in Nafenopin-treated rats since this drug (which causes a marked proliferation of hepatic peroxisomes) also increases carnitine acetyl-transferase activity 100 fold and doubles the activity of catalase. While Nafenopin treatment did not qualitatively alter the physiologic and metabolic responses of rats to turpentine, carnitine acetyltransferase

activity was decreased by 45 per cent within 48 hours of administration of turpentine (Table 3). This response was quantitatively and temporally similar to that observed for catalase.

KINETICS OF CATALASE SYNTHESIS AND DEGRADATION

The rate of catalase catabolism (K_d) was determined by using AIA to block catalase for the next 48 hours. In a semilogarithmic plot of the data (Fig. 1) straight lines are obtained from which the calculated half-life of catalase in control rats is 1.31 days (99 per cent confidence limits equal 1.22 to 1.42) while that in experimental rats was 0.95 days (99 per cent confidence limits equal 0.87 to 1.04 days). From these values the first order rate constant (K_d) for catalase destruction, calculated from the relationship $K_d = \ln 2/T_{1/2}$ are 0.0220 and 0.0304 for control and experimental rats respectively.

Although the rate of synthesis (K_s) of catalase in control animals can be calculated from the relationship $K_s = K_d D_N$, that of experimental rats cannot because the basal steady state activity (C_N) of catalase in turpentine-treated rats is unknown. Hence, the rate of synthesis was determined from the rate at which catalase activity returned following aminotriazole treatment (Fig. 2). The *in vivo* injection of AT rapidly caused a 95 per cent decrease in liver catalase activity resulting from the formation of an irreversible complex with the enzyme. Following a lag period of approximately 10 hours, during which excess AT was excreted, there was a return of catalase activity due to *de novo* synthesis of the enzyme. The rate of return of catalase activity can be approximated by comparison of the experimental data to a theoretical curve described by the relationship (41):

$$C_t = \frac{K_s}{K_d} (1 - \text{EXP}^{-K_d t}) \quad \text{eq. (1)}$$

The experimental data for control rats fit the theoretical curve on assuming a K_s of 17.5 units of catalase per hour (Fig. 2). In turpentine-treated rats, two distinct rates of catalase synthesis were evident. During the first 65 hours following the administration of turpentine, the rate of synthesis was equivalent to 7 units per hour, which when compared to control rats represented a 60 per cent reduction in the rate of synthesis. Subsequent to this initial period the rate appeared equivalent to that of the control group (Table 4).

The change in rate of catalase synthesis occurred at approximately the same time as the change in the concentration of the acute-phase serum protein MFP. This observation supports an earlier suggestion that the synthesis of acute-phase serum protein during infection and inflammation may occur at the expense of peroxisomal protein synthesis (8).

Fig. 3 shows the change in catalase activity, with respect to time, that would be expected from the calculated rates of destruction (curve B) or synthesis, (curve C), of the enzyme, either alone or together (curve D), following turpentine administration. It is calculated that the change in rate of synthesis can account for 76 per cent of the loss of catalase activity by 72 hours post-turpentine injection.

EFFECT OF INFLAMMATION ON LIPID METABOLISM

Since it has been postulated that peroxisomes may have a role in lipid metabolism, freshly isolated hepatocytes were tested for their capacity to metabolize fatty acids. Shown in Table 5, hepatocytes from turpentine-treated rats oxidized the added fatty acids, oleate, palmitate, and octanoate to $^{14}\text{CO}_2$ at a significantly lower rate than control hepatocytes. On the other hand, incorporation of ^{14}C into esterified cellular lipids was significantly increased when compared to control cells.

DISCUSSION

Depression of liver catalase activity has been a consistent finding in hosts with bacterial infections or sterile inflammatory lesions (1, 8, 34). A decrease in liver catalase activity in tumor-bearing rats, subsequently shown to result from bacterial contamination of the tumor (19, 20), was found to be related to a reduction in the absolute concentration of the enzyme protein (33). The results obtained in the present study demonstrate that while catalase catabolism is slightly increased, the depression in activity during the acute phase of the inflammatory reaction results primarily from a 60 per cent reduction in the rate of synthesis of the enzyme.

The depressions of urate oxidase, hydroxy acid oxidase, D-amino acid oxidase and carnitine acetyltransferase activity which were temporally similar to the change in catalase activity suggests that the synthesis of these enzymes may be similarly reduced. A decrease in synthesis of peroxisomal enzymes may thus result in reduction of the actual number of liver peroxisomes such as has been reported to occur during pneumococcal sepsis (8).

Nishimura et al. (34) suggested that the depression in hepatic catalase occurring after subcutaneous injury may be mediated by release of an intermediate substance at the site of injury, which when transported to the liver, effects the synthesis of the enzyme. Such an intermediary substance has been shown to be released from phagocytic cells following their ingestion of microorganisms or necrotic tissue (2). The leukocytic mediator can elicit the nonspecific acute-phase reactions associated with infection and inflammation by stimulating hepatic RNA synthesis, amino acid flux and synthesis of acute-phase globulins (48). In addition,

leukocyte-derived factors had been shown to cause an array of physiological alterations in a traumatized host which include fever (42), increased plasma copper (37), ceruloplasmin (37), glucagon and insulin (12).

Since the alterations in peroxisomal enzyme activities during the turpentine-induced inflammatory response appear temporally related with expression of the known acute-phase reactants, we propose that the depression of peroxisomal activity is another nonspecific host response to infection and inflammation. That this effect is a nonspecific response to tissue injury and not a toxic effect of turpentine is supported by the similarity of the peroxisomal response following subcutaneous injections of talcum powder (34, unpublished observations), bacterial infections (8), and partial hepatectomy (23). Whether the peroxisomal response is a direct effect of a leukocytic mediator remains to be determined.

Similarly obscure is the survival value of such an adaptation. The reduced levels of peroxisomal enzyme activity may represent biochemical lesions which contribute to cellular dysfunction. Alternatively, the observed enzymatic changes may represent a normal response to inflammation which is of some yet undetermined benefit to the host. The possibility also exists that peroxisomes may contribute little to cellular homeostasis and their synthesis may become expendable or subordinate to synthesis and release by hepatocytes of acute-phase serum proteins.

The difficulty in differentiating between these possibilities results from our incomplete understanding of the precise role of peroxisomes in cellular metabolism. Their predominance in cells associated with lipid metabolism and the inverse relationship between hepatic peroxisomal content and drugs which lower serum cholesterol and triglycerides have suggested a specific involvement for peroxisomes in lipid metabolism (4, 15, 43).

Lazarow and de Duve (25) have recently demonstrated the presence in purified peroxisomes of a cyanide-insensitive fatty acetyl-CoA oxidizing system using oxygen and NAD as electron acceptors. The activity of this system increased approximately 10 times in rats treated with an antihyperlipidemic drug (clofibrate) which is known to cause peroxisomal proliferation. The observed reduction in the rate of fatty acid oxidation by hepatocytes isolated from turpentine-treated rats, as well as septic infected rats (unpublished observations), may be the result of a decrease in activity of the peroxisomal fatty acetyl-CoA oxidizing system. This possibility is intriguing in light of the observation that mitochondria isolated from infected rats oxidize fatty acids in vitro equally well as control mitochondria (32).

Consistent with a role for peroxisomes in lipid metabolism are observations which suggest the existence of an inverse relationship between peroxisomal activity and the capacity of the liver to synthesize cholesterol and esterify fatty acids. As outlined in Table 6, rats treated with antihyperlipidemic drugs show an increase in peroxisomes, catalase, carnitine acetyltransferase and fatty acid oxidation, and a decreased capacity to synthesize cholesterol and triglycerides. In contrast, conditions such as infection and inflammation which are accompanied by a reduction of hepatic peroxisomes are associated with a pattern of lipid metabolism which is inversely related to that induced by antihyperlipidemic drugs. The possibility therefore exists that peroxisomal proliferation and fatty acid oxidation, on the one hand, and cholesterol and triglyceride synthesis, on the other, may be linked genetic functions whose level of activity and expression are inversely modulated by mediators of inflammation and antihyperlipidemic drugs.

Although the significance of these relationships as well as the real extent to which peroxisomal activity contributes to altered patterns of hepatic lipid metabolism during infection and inflammation remains to be determined, this study has served to identify a decrease in hepatic peroxisomal activity as another nonspecific acute response of a host to infection and inflammation. Furthermore, the inflammation-induced modification of peroxisomal activity offers a new experimental approach to evaluate further the contribution of these organelles to cellular metabolism.

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REFERENCES

1. Baum JH, Nishimura ET: Alterations in fine structure of liver cells during depressed catalase synthesis in the mouse. *Cancer Res* 24:2001, 1964
2. Beisel WR: Metabolic response to infection. *Annu Rev Med* 26:9, 1975
3. Berry MN: High-yield preparation of morphologically intact isolated parenchymal cells from rat liver. In *Methods in Enzymology*, edited by Fleischer S, Packer L., Vol 32, p 625. New York, Academic Press, 1974
4. Black VH, Bogart BI: Peroxisomes in inner adrenocortical cells of fetal and adult guinea pigs. *J Cell Biol* 57:345, 1975
5. Canonico PG, Ayala E, Rill WL, Little JS: The effects of pneumococcal infection on rat liver microsomal enzymes and lipogenesis by isolated hepatocytes. *Am J Clin Nutr* (In Press), 1977
6. Canonico PG, Bird, JWC: Lysosomes in skeletal muscle tissue. Zonal centrifugation evidence for multiple cellular sources. *J Cell Biol* 45:321, 1970
7. Canonico PG., Powanda MC, Cockerell GL, Moe JB: Relationship of serum β -glucuronidase and lysozyme to pathogenesis of tularemia in immune and nonimmune rats. *Infect Immun* 12:42, 1975
8. Canonico PG, White JD, Powanda MC: Peroxisome depletion in rat liver during pneumococcal sepsis. *Lab Invest* 33:147, 1975
9. Capuzzi DM, Lackman RD, Uberti MO, Reed MA: Stimulation of hepatic triglyceride synthesis and secretion by clofibrate. *Biochem Biophys Res Commun* 60:1499, 1974
10. Fallon HJ, Adams LL, Lamb RG: A review of studies on the mode of action of clofibrate and betabenzalbutyrate. *Lipids* 7:106, 1972

11. Folch J, Lees M, Sloane Stanley GH: A simple method for the isolation and purification of total lipides from animal tissues. *J Biol Chem* 226:497, 1957
12. George DT, Abeles FB, Powanda MC: Alterations in plasma glucose, insulin and glucagon induced by a leukocyte derived factor(s). *Clin Res* 23:320A, 1975
13. Goldenberg H, Hüttinger M, Kampfer P, Kramer R, Pavelka M: Effect of clofibrate application on morphology and enzyme content of liver peroxisomes. *Histochemistry* 46:189, 1976
14. Gould RG, Swyryd, EA, Coan BJ, Avoy DR: Effects of chlorophenoxyisobutyrate (CPIB) on liver composition and triglyceride synthesis in rats. *J Atheroscler Res* 6:555, 1966
15. Herzog V, Fahimi HD: Microbodies (peroxisomes) containing catalase in myocardium: morphological and biochemical evidence. *Science* 185:271, 1974
16. Hruban Z, Rechcigl M: Microbodies and Related Particles. New York, Academic Press, 1969
17. Kampschmidt RF, Upchurch HF: The effect of endogenous pyrogen on the plasma zinc concentration of the rat. *Proc Soc Exp Biol Med* 134:1150, 1970
18. Kampschmidt, RF, Upchurch HF: Lowering of plasma iron concentration in the rat with leukocytic extracts. *Am J Physiol* 216:1287, 1969
19. Kampschmidt RF, Upchurch HF: Effect of bacterial contamination of the tumor on tumor-host relationships. *Cancer Res* 23:756, 1963
20. Kampschmidt RF, Schultz GA: Absence of toxohormone in rat tumors free of bacterial contamination. *Cancer Res* 23:751, 1963

21. Lakshmanan MR, Phillips WEJ, Brien RL: Effect of p-chlorophenoxyisobutyrate (CPIB) fed to rats on hepatic biosynthesis and catabolism of ubiquinone. *J Lipid Res* 9:353, 1968
22. Lamb RG, Fallon HJ: Inhibition of monoacylglycerophosphate formation by chlorophenoxyisobutyrate and β -benzalbutyrate. *J Biol Chem* 247: 1281, 1972
23. Lamy J, Lamy JN, Schmitt M, Weill J: Effet d'une hépatectomie minimale sur l'activité de la catalase et des oxydases peroxysomales du foie de rat. *Biochimie* 55:1491, 1973
24. Lamy JN, Lamy J, Schmitt M, Weill J: Sur la diminution de la vitesse de biosynthèse de la catalase hépatique chez le après hépatectomie minimale. *Bull Soc Chem Biol (Paris)* 52:229, 1970
25. Lazarow PB, de Duve C: A fatty acyl-CoA oxidizing system in rat liver peroxisomes; enhancement by clofibrate, a hypolipidemic drug. *Proc Natl Acad Sci USA* 73:2043, 1976
26. Leighton F, Poole B, Beaufay H, Baudhuin P, Coffey JW, Fowler S, de Duve C: The large scale separation of peroxisomes, mitochondria, and lysosomes from the livers of rats injected with Triton WR-1339. Improved isolation procedures, automated analysis, biochemical and morphological properties of fractions. *J Cell Biol* 37:482, 1968
27. Lowry OH, Rosebrough NJ, Farr AL, Randall RJ: Protein measurement with the Folin phenol reagent. *J Biol Chem* 193:265, 1951
28. Luck H: Catalase. In *Methods of Enzymatic Analysis*, edited by Bergmeyer HU, p 885. New York, Academic Press, 1963
29. Markwell MAK, McGroarty EJ, Bieber LL, Tolbert NE: The subcellular distribution of carnitine acyltransferases in mammalian liver and kidney. A new peroxisomal enzyme. *J Biol Chem* 248:3426, 1973

30. Miyazawa S, Sakurai T, Imura M, Hashimoto T: Effects of ethyl p-chlorophenoxyisobutyrate on carbohydrate and fatty acid metabolism in rat liver. *J Biochem (Tokyo)* 78:1171, 1975
31. Moody DE, Reddy JK: Increase in hepatic carnitine acetyltransferase activity associated with peroxisomal (microbody) proliferation induced by the hypolipidemic drugs, clofibrate, nafenopin and methyl clofenapate. *Res Commun Chem Pathol Pharmacol* 9:501, 1974
32. Neufeld HA, Pace JA, White FE: The effect of bacterial infections on ketone concentrations in rat liver and blood and on free fatty acid concentrations in rat blood. *Metabolism* 25:877, 1976.
33. Nishimura ET, Kobara TY, Kaltenbach JP, Wartman WB: Immunological evidence of repressed catalase synthesis in livers of tumor-bearing mice. *Arch Biochem Biophys* 97:589, 1962
34. Nishimura ET, Rosenheim S, Klein L: Depression of hepatic catalase in mice after subcutaneous injury. *Lab Invest* 12:415, 1963
35. Osserman EF, Lawlor DP: Serum and urinary lysozyme (muramidase) in monocytic and monomyelocytic leukemia. *J Exp Med* 124:921, 1966
36. Pekarek RS, Beisel WR: Effect of endotoxin upon serum zinc concentrations in the rat. *Appl Microbiol* 18:482, 1969
37. Pekarek RS, Powanda MC, Wannemacher RW Jr: The effect of leukocytic endogenous mediator (LEM) on serum copper and ceruloplasmin concentrations in the rat. *Proc Soc Exp Biol Med* 141:1029, 1972
38. Powanda MC, Canonico PG: Protective effect of clofibrate against S. pneumoniae infection in rats. *Proc Soc Exp Biol Med* 152:437, 1976
39. Powanda MC, Henriksen EL, Ayala E, Canonico PG: Clofibrate-induced alterations in serum protein patterns. *Biochem Pharmacol* 25:785, 1976
40. Powanda MC, Wannamacher RW Jr, Cockerell GL: Nitrogen metabolism and

- protein synthesis during pneumococcal sepsis in rats. *Infect Immun* 6:266, 1972
41. Price VE, Sterling WR, Tarantola VA, Hartley RW Jr, Rechcigl M Jr: The kinetics of catalase synthesis and destruction in vivo *J Biol Chem* 237:3468, 1962
 42. Rafter GW, Cheuk SF, Krause DW, Wood WB Jr: Studies on the pathogenesis of fever. XIV. Further observations on the chemistry of leukocytic pyrogen. *J Exp Med* 123:433, 1966
 43. Reddy JK: Possible properties of microbodies (peroxisomes). Microbody proliferation and hypolipidemic drugs. *J Histochem Cytochem* 21:967, 1973
 44. Reddy J, Svoboda D, Azarnoff D: Microbody proliferation in liver induced by nafenopin, a new hypolipidemic drug: comparison with CPIB. *Biochem Biophys Res Commun* 52:537, 1973
 45. Reddy JK, Azarnoff DL, Svoboda DJ, Prasad JD: Nafenopin-induced hepatic microbody (peroxisome) proliferation and catalase synthesis in rats and mice. *J Cell Biol* 61:344, 1974
 46. Sarcione EJ: Synthesis and secretion of α_2 -(acute phase) globulin by the isolated perfused liver from injured adult rats. *Biochemistry* 9:3059, 1970
 47. Thompson WL, Wannemacher WR Jr: Effects of infection with Diplococcus pneumoniae on synthesis of ribonucleic acids in rat liver. *Biochem J* 134:79, 1973
 48. Wannemacher RW Jr, Pekarek RS, Thompson WL, Curnow RT, Beall FA, Zenser TV, DeRubertis FR, Beisel WR: A protein from polymorphonuclear leukocytes (LEM) which affects the rate of hepatic amino acid transport

and synthesis of acute-phase globulins. *Endocrinology* 96:651, 1975

49. Weimer HE, Benjamin DC: Immunological detection of an acute-phase protein in rat serum. *Am J Physiol* 209:736, 1965

TABLE 1. PHYSIOLOGIC AND METABOLIC RESPONSES IN RATS FOLLOWING TURPENTINE INJECTION

Parameter	Mean Values + S.E. by days post-turpentine injection ^a				
	0	1	2	3	5
Body temperature °C.	37.2 ± 0.1	38.9 ± 0.3 ^b	37.5 ± 0.1	37.0 ± 0.1	37.8 ± 0.2
WBC (x 10 ⁻³ /mm. ³)	6.22 ± 0.48	4.00 ± 0.29 ^c	4.35 ± 0.49 ^d	3.94 ± 0.29 ^c	6.66 ± 0.75
PNN (%)	16.8 ± 2.6	14.0 ± 2.8	4.3 ± 2.0 ^c	17.2 ± 5.0	29.2 ± 5.5 ^d
Plasma Fe (µg./dl.)	315 ± 17	151 ± 13 ^b	328 ± 9	315 ± 14	376 ± 18 ^d
Plasma Zn (µg./dl.)	125 ± 6	86 ± 4 ^b	86 ± 4 ^b	74 ± 7 ^b	113 ± 17
Plasma α ₂ -MFP (mg./ml.)	1.1 ± 0.3	35.8 ± 7.8 ^b	62.6 ± 14.3 ^b	26.2 ± 6.3 ^b	14.0 ± 4.6 ^b
Plasma lysozyme (µg./ml.)	2.5 ± 0.3	3.3 ± 0.1	4.1 ± 0.2 ^c	3.7 ± 0.2	4.3 ± 0.2 ^b
Plasma β-Glucuronidase (U/dl.)	57.5 ± 6.4	86.8 ± 10.8 ^d	60.1 ± 4.2	37.7 ± 3.5	53.3 ± 5.7

^a N = 10 for day 0, 5 for days 1-5.

^b $P < 0.001$

^c $P < 0.01$

^d $P < 0.05$

TABLE 2. HEPATIC PEROXISOMAL ENZYME ACTIVITIES FOLLOWING TURPENTINE INJECTION

Enzyme	Milliunits \pm S.E. by days post-turpentine injection ^a				
	0	1	2	3	5
Catalase	795 \pm 28	607 \pm 51 ^c	400 \pm 46 ^b	319 \pm 9 ^b	668 \pm 2 ^c
Urate oxidase	4.41 \pm 0.29	4.12 \pm 0.39	3.36 \pm 0.57	2.89 \pm 0.36 ^d	5.03 \pm 0.22
D-amino acid oxidase	7.61 \pm 0.76	6.41 \pm 0.28	4.56 \pm 0.34 ^d	5.07 \pm 0.21 ^d	4.78 \pm 0.53 ^d
Hydroxy-acid oxidase	12.4 \pm 0.92	10.2 \pm 0.69	6.79 \pm 0.13 ^c	6.67 \pm 0.17 ^b	6.77 \pm 0.39 ^b

^a N = 10 for day 0, 5 for days 1-5

^b $P < 0.001$

^c $P < 0.01$

^d $P < 0.05$

TABLE 3. PHYSIOLOGIC AND METABOLIC RESPONSES IN NAFENOPIN-FED RATS FOLLOWING TURPENTINE INJECTION

Parameter	Mean \pm S.E. by days post-turpentine injection ^a				
	0	1	2	3	5
Body temperature °C.	37.1 \pm 0.2	39.5 \pm 0.2 ^b	38.1 \pm 0.2 ^c	37.5 \pm 1	37.7 \pm 0.2
WBC ($\times 10^{-3}/\text{mm.}^3$)	6.94 \pm 0.47	3.52 \pm 0.31 ^b	3.92 \pm 0.23 ^b	6.14 \pm 0.64	6.20 \pm 0.66
PMN (%)	16.2 \pm 3.1	12.0 \pm 2.7	3.1 \pm 1.8 ^c	12.0 \pm 0.6	16.1 \pm 1.6
Plasma Fe (ug./dl.)	314 \pm 12	159 \pm 18 ^b	225 \pm 18 ^d	227 \pm 16	302 \pm 17
Plasma Zn (ug./dl.)	116 \pm 3	70 \pm 2 ^b	39 \pm 2 ^b	89 \pm 4 ^b	91 \pm 3 ^b
Plasma α_2 -MFP (mg./ml.)	0.5 \pm 0.3	13.0 \pm 1.8 ^b	22.6 \pm 5.3 ^b	25.2 \pm 4.1 ^b	8.0 \pm 3.0 ^c
Plasma lysozyme (ug./ml.)	2.5 \pm 0.1	3.2 \pm 0.1 ^b	4.2 \pm 0.3 ^b	4.4 \pm 0.3 ^b	4.0 \pm 0.2 ^b
Plasma β -Glucuronidase (U/dl.)	72.7 \pm 7.1	115.8 \pm 8.5 ^c	107.2 \pm 4.7 ^c	73.0 \pm 7	75.0 \pm 12.3
Catalase (mU)	1573 \pm 28	1125 \pm 79 ^c	991 \pm 106 ^b	869 \pm 35 ^b	1160 \pm 118 ^b
Carnitine acetyltransferase (U/mg. protein)	60.9 \pm 5.3	42.7 \pm 4.4	35.0 \pm 0.3 ^c	37.3 \pm 9.3 ^d	41.5 \pm 4.4 ^d

^a N = 10 for day 0, N = 5 for days 1-5.^c $p < 0.05$ ^b $p < 0.001$ ^d $p < 0.05$

TABLE 4. CALCULATED RATES FOR CATALASE DESTRUCTION AND SYNTHESIS
FOLLOWING TURPENTINE INOCULATION.

Hours Post-turpentine	Rate of destruction (K_d)	Rate of synthesis (K_s)	Corresponding curve in Fig. 2
	<u>% per hour</u>	<u>mU per hour</u>	
CONTROL	2.20	17.5	A
10 - 65	3.04	7.0	B
65+	2.20	17.5	C

TABLE 5. METABOLISM OF FATTY ACIDS BY ISOLATED HEPATOCYTES FROM CONTROL AND TURPENTINE-TREATED RATS.

Fatty acid		nmol. substrate converted/hour/5 x 10 ⁶ cells ± S.E. (N)	
Substrate	Metabolic parameter	Control rats	Turpentine-treated rats
Oleate		7.31 ± 0.41 (9)	3.74 ± 0.29 (9) ^a
Palmitate	¹⁴ C ₂ Production	6.13 ± 1.09 (9)	3.53 ± 0.28 (9) ^a
Octanoate		2.06 ± 0.19 (9)	1.61 ± 0.70 (9) ^a
Oleate		11.24 ± 1.00 (21)	15.65 ± 1.40 (18) ^b
Palmitate	¹⁴ C-esterified	4.52 ± 0.31 (21)	6.73 ± 0.37 (18) ^a
Octanoate	cell lipid	0.80 ± 0.06 (18)	1.31 ± 0.05 (21) ^a

Substrate consisted of 2 μ Ci. of [1-¹⁴C] labeled fatty acid and 2mM unlabeled fatty acid complexed at a molar ratio of 2:1 with bovine serum albumin.

^a $p < 0.01$ ^b $p < 0.025$

TABLE 6. MODULATION OF HEPATIC AND BLOOD PARAMETERS IN RESPONSE TO
TISSUE INJURY (INFECTION OR INFLAMMATION) OR TREATMENT WITH
ANTI-HYPERLIPIDEMIC DRUGS.

Parameter	Tissue Injury	Ref.	Anti Hyperlipidemic Drugs	Ref.
Peroxisome density	- ^a	(8)	+	(43, 44)
Catalase synthesis	-	(b)	+	(45)
Carnitine acetyl- transferase activity	-	(b)	+	(13, 31)
Fatty acid oxidation	-	(32)	+	(9, c)
<u>In vitro</u> peroxisomal fatty acid oxidation			+	(25)
Blood ketone bodies	-	(32)	+	(30)
Cholesterol synthesis	+	(5)	-	(21)
Fatty acid esterification	+	(5, b)	- +	(10, 22) (9, 14)
Bound/free ribosome ratio	+	(47)	-	(39)
Synthesis of serum proteins	+	(40)	-	(39)
Susceptibility to <u>S.</u> <u>pneumoniae</u> infection	Uniformly lethal	(38)	Increased resistance	(38)

^a -, decreased; +, increased

^b This report

^c Unpublished observation

LEGEND TO FIGURES

Fig. 1. Kinetics of liver catalase destruction. Semilogarithmic plot of catalase activity vs. time in control and turpentine-treated rats given 20 mg. AIA per 100 gm. body weight twice daily. Turpentine was given 12 hours after the first injection of AIA.

Fig. 2. Return of liver catalase activity after injection of 3 amino-1, 2, 4-triazole. Open and closed circles represent experimental data. Solid lines are theoretical curves to fit equation 1 (in text) on assuming rates of synthesis and destruction as given in Table 5. Stippled bar represents average catalase activity \pm S.E. of rats not given aminotriazole.

Fig. 3. Theoretical curve showing the expected change in catalase activity with respect to time due to changes in the rate of synthesis (K_s) and/or destruction (K_d). Curve A, steady state value where $K_s = 17.5$ units/hour and $K_d = 2.20$ per cent/hour; Curve B, $K_d = 3.04$ per cent/hour; Curve C, $K_s = 7$ units/hours; Curve D, sum of curves B and C. Solid squares represent experimental observations as reported in Table 1.

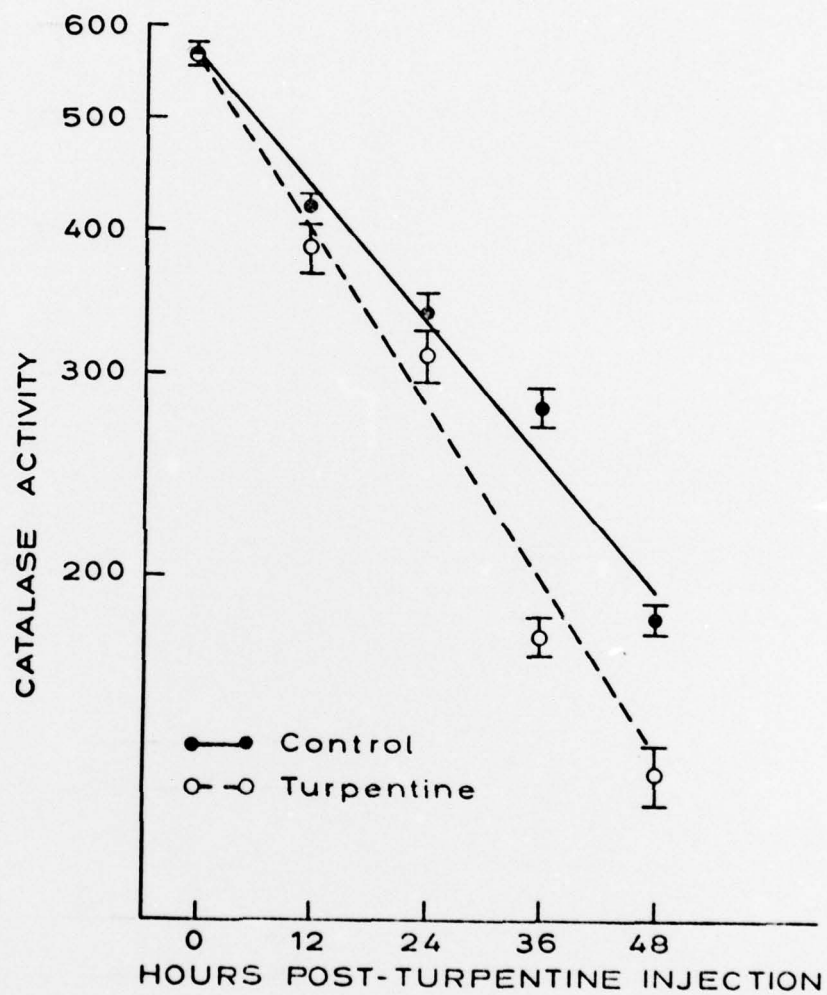


Fig 1. Cameron et al

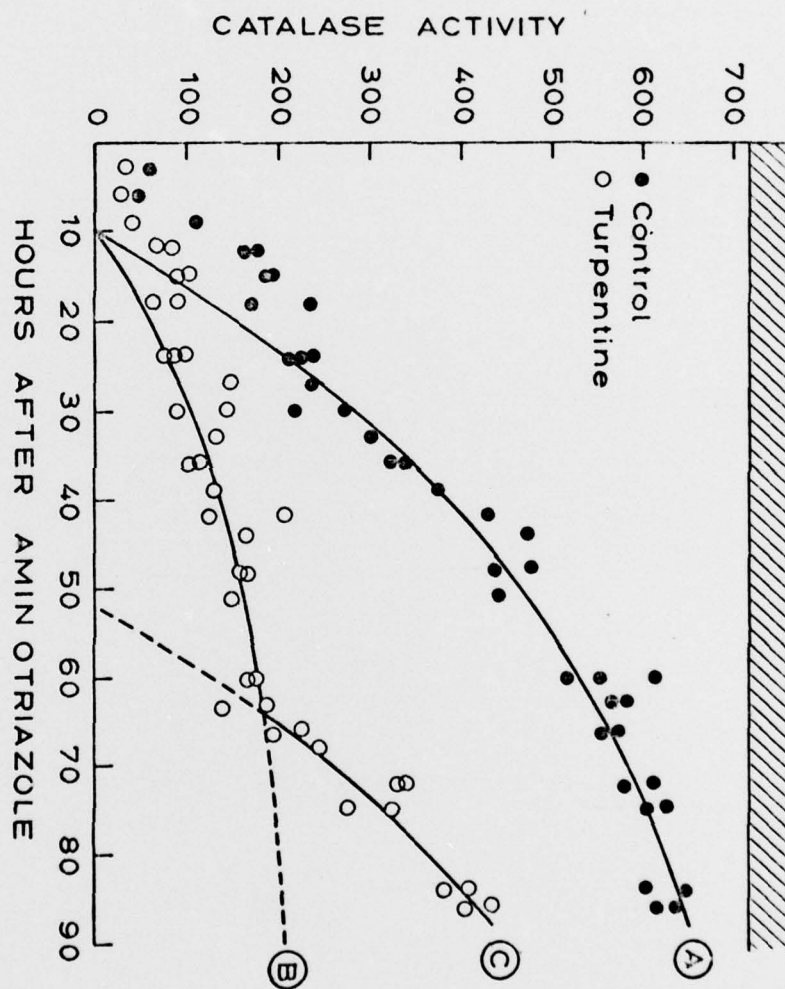


fig 2 Canones et al

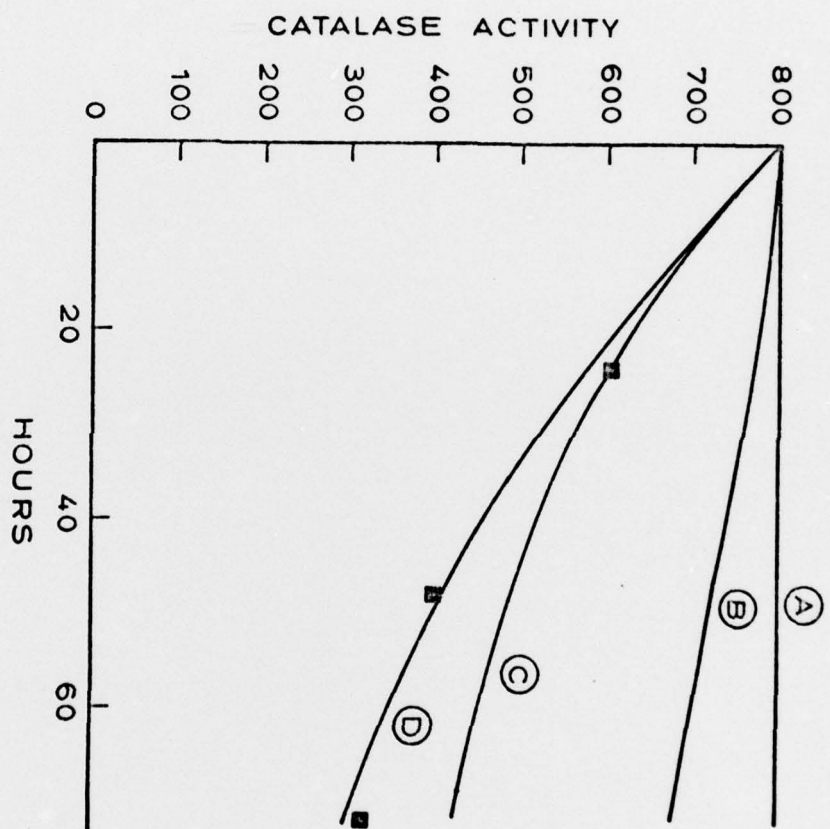


fig 3 Canonico et al